

VIII. *An Experiment proposed for determining, by the Aberration of the fixed Stars, whether the Rays of Light, in pervading different Media, change their Velocity according to the Law which results from Sir Isaac Newton's Ideas concerning the Cause of Refraction; and for ascertaining their Velocity in every Medium whose refractive Density is known. By Patrick Wilfon, A. M. Assistant to Alexander Wilfon, M. D. Professor of Practical Astronomy in the University of Glasgow; communicated by the Rev. Nevil Maskelyne, D. D. F. R. S. Astronomer Royal.*

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UPON the supposition that the refraction of light is caused by a certain action of gross and sensible bodies upon it, Sir ISAAC NEWTON has demonstrated, that the sines of incidence and refraction, when the rays pass out of one medium into another of different density, must always be in a constant ratio. This constancy of the ratio of the sines is agreeable to an universal experience, and has been called the law of refraction. Upon the same grounds he has also demonstrated, that the velocity of the rays must be greater in the more refracting medium in the inverse ratio of the sines. Of this property of refraction, however, we have hitherto had no evidence in the way of experiment. The ideas entertained by Sir ISAAC NEWTON, from which this property has been deduced, though they confess their great author, by a most beautiful simplicity, and

and by a very striking agreement with fact, have yet been deemed by some persons as not perfectly authentic. His contemporary LEIBNITZ and others have attempted demonstrations of the law of refraction from principles very different, and which do not lead to the opinion of the acceleration of light in the more refracting medium. At present it is proposed to point out a method of determining experimentally the law of the variation of the velocity of light, according to the change of the medium. If observations shall shew this law to be agreeable to Sir ISAAC NEWTON's conclusions, we shall then have a very strong additional evidence in favour of his principles. If, contrary to the most probable issue of the experiment, some unsuspected law should be discovered, we must, according to the rules of induction laid down by that great master in philosophy, so far restrict our general conclusions, and accommodate our ideas to the real condition of things.

The method of experiment at present alluded to is, that of observing the aberration of the fixed stars with a telescope filled with a dense fluid, such as water, or any other equally limpid and of greater refraction, fitted to bring the rays to a focus by the surface of the medium opposed to the object having a proper degree of convexity. It is enough at this time to suggest a general notion of the instrument, and we now proceed to explain in what manner it can assist us in the present inquiry.

Since aberration, taken in its enlarged sense, depends on the relative velocities of light and of the telescope, if the rays were really to move much faster or much slower in an unusual telescope of this kind, it seems to follow, that the quantity of aberration given in these circumstances, compared with Dr. BRADLEY's angle, would certainly indicate the new rate of velocity. Such an inference would certainly be just, and it is

upon these grounds that we propose to inquire into the velocity of the rays, as they move forward in dense media so applied to telescopes. Granting, however, for the sake of argument, that light moves down through such an unusual telescope with an increased velocity suited to the refractive density of the medium, it will by no means happen, that the aberration will be changed on that account. This proposition, which at first view may appear paradoxical, and even contradictory to what has been affirmed above, is however not the less certain, and may serve to shew, what caution is sometimes requisite in applying general principles to particular cases: for it shall be proved, that the aberration in such a telescope will precisely agree with that of Dr. BRADLEY's only in the case of the rays moving swifter in the watery medium than in air, in the ratio assigned by Sir ISAAC NEWTON, and that this sameness of aberration will itself be a proof of light being so accelerated within the telescope.

In the illustrations which follow, the reader is supposed not to be wholly unaccustomed to the distinctions betwixt absolute and relative motion, as this will prevent repetitions and all unnecessary prolixity.

Let ABC (fig. 1.) be the spherical refracting surface of such a telescope as has been described, and let the telescope be supposed to be at rest, or the velocity of light to be infinite with respect to that of the earth, and let GBMF be a line drawn from a star at G, in the pole of the ecliptic, through the center M of the refracting surface; the image of the star will be formed somewhere, as at F, in the line BF; and here the intersection of the cross wires made use of in observing must be placed. It is evident, that the star will be seen in its true direction FG; and we must conclude that to be its true direction, because we know

know that the ray GBF passes into the medium without being refracted by it, and BMF would be considered as the axis of the telescope.

Now let the spherical refracting surface with its wires, or the unusual telescope be carried laterally with the motion of the earth towards Q. Conceive GBF to be a line not partaking of this lateral motion, which at any particular moment passes thro' M, the center of convexity. Along this line suppose one of ~~many~~ rays to pass from a star situated in the pole of the ecliptic. Then will all the contemporary light of this pencil of parallel rays be made to converge so as to meet in a focus somewhere in the unrefracted ray BF. Let F therefore be the point in absolute space where the image of the star is so formed. Let the parallel motion of the telescope, whose refracting spherical surface is ABC, be in the direction of HF, and take FD to FB as the lateral velocity of the telescope to the velocity of light in air, and join BD: then it is manifest, that BD will be the position of a telescope such as Dr. BRADLEY's, when the image of the star is formed in the axis BD, and that IBG, or its equal FBD, will be the angle of greatest aberration.

Moreover, the velocity of the rays as they proceed to the focus F, after refraction at the surface ABC, being supposed the same as in air, it is evident, that the line DML drawn through D, and through the center of convexity M, must give the position of the axis of this kind of telescope, when the image of the star is formed there: for, by hypothesis, the image is formed in F in absolute space, and since BF is supposed to be to FD, as the velocity of light within the medium to the lateral velocity of the telescope, the point D of the axis DL will arrive at F, when the rays arrive there to form

the image. And the observer not knowing, or at present not taking account of, the lateral motion of the telescope, will suppose, that the line LMD joining the image of the star and the center of convexity M is the true direction of the star; just as before he concluded, that FMBG would be the direction of the star when the lateral motion of the telescope was supposed to be nothing. Hence it is evident, that the intersection of the cross wires, made use of in observing, must now be placed at D; or else, if those be still used that were before supposed to be at F, the refracting surface ABC with the line or axis BF must revolve about the center M till the vertex B comes to L and the cross wires F to D.

In like manner, if the velocity of the rays were increased after refraction at the spherical surface in any ratio, as that of DF to EF, the refraction continuing the same, then EMO drawn through the center of convexity would now give the position of the axis of the telescope necessary for receiving the image formed at F. For the space described by the rays in passing downwards to the focus, in this case and the former being equal, the times of their converging at F will be reciprocally as the velocities, or as EF to DF. But, on account of the equable lateral motion of the telescope, DF and EF will be as the times of the points D and E arriving at F; therefore, in the last case, the intersection of the cross wires supposed at E will meet the image at F, and accordingly the star will be seen in the axis.

Fig. 2. From what has been said it will appear, that if DF be taken to EF, as the sine of incidence to the sine of refraction peculiar to the medium which fills the telescope; then, from the property of the focus, we shall have this proportion, *viz.* $BF : FM :: DF : EF$. Hence the line EMO passing through

through M must be parallel to DB; but DB, as before, denotes the position of Dr. BRADLEY's telescope, when the aberration of the star is at its maximum, and EMO parallel to it, denotes the position of the water telescope, at the same time, upon the supposition that the velocity of the rays without and within be as EF to DF, or inversely, as the sines of incidence and refraction peculiar to water. Here then we discover what must be the law of variation as to the velocity of the rays, provided that the aberration given by such a telescope shall come out the same with that found by Dr. BRADLEY. It is the very same which follows from the Newtonian principles: for from the manner of observing, the angle of aberration is always determined by the position of the telescope necessary for having the image formed somewhere in the axis.

But supposing that in the course of observing with such a telescope, the aberration should come out different from what has already been ascertained by Dr. BRADLEY, it may next be enquired, how from the difference given the velocity of light within the telescope is to be deduced.

Fig. 3. Imagine then such a telescope actually to give FMD as the greatest angle of aberration, and let this be supposed greater than that of Dr. BRADLEY's, which, for example, let be FME. From what has been already said, the velocity of light corresponding to this last mentioned angle, is deducible from the known refraction of the medium which fills the telescope; and, by construction, the velocity corresponding to FMD, the angle given, must be to the former inversely as the tangents of these angles. From this consideration we have the following analogy for finding the velocity corresponding to whatever difference there may be observed between the two aberrations at present alluded to. The rule in all cases must be;

“ as the tangent of the observed angle is to the tangent of the
 “ Bradleyan angle, so is the velocity of light deducible from
 “ the hypothesis of the observed angle being the same with
 “ that of Dr. BRADLEY to the velocity sought.” It has already
 been shewn, how the former of these velocities can be universally
 ascertained, from the known refraction of the medium which
 is taken to fill the telescope, and therefore the last term of the
 above proportion, which is the velocity sought, is thereby
 given.

Fig. 2. In a telescope of this kind it will not have escaped
 notice, that the ray BF, which, on account of its passing to
 the focus unrefracted, may be called the axis of the pencil,
 can never be found in the axis of the telescope EO, except at
 the focus F, where D and F meet. That ray, however, OP,
 parallel to BG, which falls obliquely on the axis of the tele-
 scope EO, will continue to pass along it after refraction, and
 for that reason it may be called the relative axis of the pencil.

This will appear, by considering that the particle of light,
 which at any moment is refracted at the vertex O of the spheri-
 cal surface, is found by hypothesis in the axis a second time,
 when it meets the cotemporary light at the focus. But since
 both the motion of the axis and of the particle is uniform and
 rectilinear, the former cannot be found in the latter at two
 different times, without being found in it continually during
 the whole interval. In like manner, a part of every other ray
 from the star, which successively falls upon the vertex, must
 move relatively along the axis after refraction: and thus a con-
 stant succession of these particles constitute a visual refracted
 ray, whose relative path must always be in the axis OE.

All that has been shewn concerning the telescope already
 considered, will receive still further illustration, by tracing the
 motion

motion of this particular refracted ray till it arrives at the focus. This way of viewing the subject will also render the reasoning more general, and make it apply to telescopes when the dense fluid within is supposed to be confined by object-glasses of any figure. But in order to this, it will be convenient to premise, and briefly to demonstrate, what shall afterwards be referred to by the name of

P R O P. A.

Fig. 4. If any very small body or particle of light as it moves uniformly in the absolute path SB, has passed relatively along a part of the line CD, which advances equably and parallel to itself in the direction DK; and if at any instant the absolute path of the particle be changed into any other, as BR; I say, it will still pass relatively along the moving line, provided its velocity now be to its former velocity as the sine of the angle DBF to the sine of the angle DBR; these being the angles which the moving line BD makes with BF and BR the absolute path or direction of the particle in the two cases.

The construction of this figure is so simple, that it is unnecessary formally to point it out. Since, by hypothesis, the velocity of the particle along BR is to its former along BF as the sine FZ to the sine RT; or, on account of similar triangles, as DF to IR, and, on account of parallels, as DF to DW, it follows, that the time of its describing BR now, is to the time of formerly describing its equal BF, as DW to DF. But the line BD advancing with a uniform motion, the time of its arriving at W is to the time of its arriving at F, also as DW to DF. Therefore, when the particle arrives at R, the point D of the moving line will have arrived at W, and WRP will be its position. Hence the particle at that moment must be found in the intersection R of this line, with its absolute path BR. In the

same manner it may be shewn, that at any other time the particle will be found in the intersection: it, therefore, from the time of its direction being changed at B, must pass relatively along the moving line as before. By a small alteration in the construction it may be shewn, that if the absolute path had been so changed at B as to have augmented the angle FBD, still the particle would have moved relatively along DB, provided its velocity after had been to its velocity before as the sine of FBD the first angle to the sine of the increased angle.

To apply, therefore, this proposition to the present investigation, let DB be conceived as the axis of a telescope perpendicular to the spherical surface of a refracting medium which accompanies it in its lateral motion, SB the absolute path of a particle of light which had passed relatively along DB produced, till its arrival at B, and BR its absolute path within the medium of the telescope. Then it is evident, that FBD, or its equal CBS, will be universally the angle of incidence, and RBD the angle of refraction. Hence, by prop. A. that ray of the parallel pencil which is refracted at O, the vertex of the spherical surface in fig. 2. must still pass relatively along the axis, provided the velocity within the telescope be to its former in air, as the sine of incidence to the sine of refraction. But the image of the star being produced by the meeting of all the contemporary light, will consequently be found in the axis, which, by hypothesis, deviates from the true place of the star by the same quantity as Dr. BRADLEY's angle; so that in this way of considering the matter, the same thing results which was formerly shewn in regard to a telescope so constructed.

By prop. A. it is also manifest, that whatever number of refractions that ray which falls upon the extremity of the axis suffers in pervading object-glasses of any figure, or even dense media,

media beyond the object-glass if bounded by transparent planes to which the axis produced is perpendicular, yet if the velocities and refractions so correspond, still the ray in question will pass relatively along the axis till it meet the rest at the focus: for here the refracted ray in the first medium becomes the incident ray in relation to its path in the second, and this in its turn becomes an incident ray in relation to its path in the third medium, &c. and therefore by the prop. A. can never deviate from the moving axis whatever be the refractive density of the media, or however these are disposed in the order of succession. And since, by Sir ISAAC NEWTON's theorem, the ratio of the sine of incidence to the sine of refraction in the passage of a ray out of one medium into another, is compounded of the ratio which the former has to the latter in the passage of that ray out of the first medium into any third, and of the ratio of the former to the latter in the passage of the same ray out of the third medium into the second, &c. it follows, that if the velocities be related to the degree of refraction as before mentioned, the ray in the last dense medium will, notwithstanding any number of previous refractions by glasses, &c. have the same final velocity that would have been acquired on its passing immediately out of air into that medium. This being the case, it appears, that though the intervention of an object-glass may shorten the focal distance of such a telescope, yet it will not displace the image nor alter the rule of inferring the final velocity of the rays in the dense medium from the aberration given; at least when this is supposed to be the same with Dr. BRADLEY's.

Fig. 3. But further, if the aberration of such a telescope should differ from the Bradleyan one, and give, for example, the angle OMB, still the ray PO, which falls on O the vertex, must be considered as an incident ray, which, after refraction,

passes along the axis. By prop. A. therefore, the velocity of the ray, whatever this may be after refraction, must be to that velocity by which it would have moved relatively in the axis, so inclined to its path, previous to the refraction, inversely as the sines of incidence and refraction. Now this being duly considered, it will be found that the velocity within the medium, corresponding to this supposed aberration, or the absolute velocity within the medium, must be to the velocity within the medium corresponding to the Bradleyan aberration, inversely as the tangents of these two angles: for let V and v express the velocities before and after refraction corresponding to the Bradleyan angle, and X and x the velocities before and after corresponding to the supposed uncommon angle, x being the actual velocity after refraction; then, because by prop. A. the antecedent is to the consequent, in both cases, in the same ratio, viz. as the sine of refraction to the sine of incidence, it will be $V : v :: X : x$, and therefore $V : X :: v : x$. But from the nature of the aberration V must be to X (this supposititious velocity before incidence) inversely as the tangents of the angles of the two aberrations. This therefore must be the ratio of v to x . But v is given as before shewn; therefore x the velocity within the medium corresponding to the supposed observed aberration is also given, and by the same rule as was found formerly in the case of the first telescope.

What has been at present advanced is unconnected with any hypothetical notions concerning the rays or the cause of refraction. Light has been considered only as something which moves uniformly from one place to another, and which is always refracted according to a known law. The first of these properties has been put beyond all doubt by the observations of Dr. BRADLEY and Mr. MOLYNEUX; and it is has been long known that the last is quite agreeable to experience.

It has indeed always been taken for granted, that the velocity of the ray which passes through the center of convexity, represents the common velocity of all the contemporary light of the converging pencil. This may perhaps be reckoned a circumstance of which we have no proof. But it must be considered, that if the rays of light, after being variously bent towards the focus, were no longer to move with the same common velocity, the image formed at the focus of Dr. BRADLEY's telescope, would be elongated in the direction of the aberration. Those who have attended to this subject will be at no loss in discerning the reason of this. The extent of that lengthened image would depend upon the difference of velocity which would obtain among the converging rays, and would probably increase according to the largeness of the aperture of the object-glass. But such a phenomenon being contrary to experience, it follows, that the unequal bending of the rays does not give them unequal velocities, whilst moving in the same medium. This is another property with regard to the motion of light which may be considered as proved experimentally by Dr. BRADLEY's observations, and which doubtless would have occurred to him if he had had occasion to trace the refraction of a pencil of parallel rays at the object-glass of his telescope.

To conclude: in bringing this question concerning the velocity of light to the issue of an experiment, that fluid would doubtless be most proper for the telescope which absorbs the fewest rays, and possesses the greatest refractive density, and which at the same time is not liable to generate air-bubbles. To compensate for the unavoidable loss of light, which by Mr. CANTON and Dr. PRIESTLEY's experiments is found to be considerable in such cases, it perhaps may be necessary to use an achromatic

achromatic object-glasses for the sake of a large aperture, and of such a figure as to shorten the focal distance as much as the observations of such a small angle can admit of. Some contrivance too will be requisite to keep the whole space between the object-glass and the eye-glass always full, notwithstanding the expansions and contractions of the confined fluid by heat and cold, or its waste by evaporation.

It might prove a very considerable abridgement of the necessary apparatus, if this kind of telescope could be connected with the common telescope of a mural quadrant, or zenith sector, and their axes made perfectly parallel by previous observations of a proper terrestrial object. But as there would be some room for apprehending that the exact adjustment of the axes might be affected in raising the telescopes afterwards for celestial observations, this might be examined into by directing them to some star situated in, or very near, the ecliptic, and taking its meridian altitudes at a time of the year when it is in quadrature with the sun, in which case it would have no aberration. But either in this way, or with two separate instruments, the experiment might be made in a few nights, by taking the zenith distance of a proper star, the plane of the instruments being alternately turned different ways in observing, to get the true zenith distance independent of the error of the line of collimation; or the meridian altitude of the pole star may be observed in December above and below the pole, which will give the apparent distance of the star from the pole at that time as affected by aberration. The error of the line of collimation would not affect the result in this way, being the same in the observation both above and below the pole.



Q

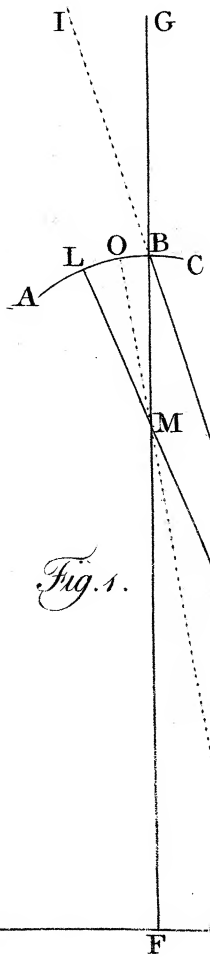


Fig. 1.

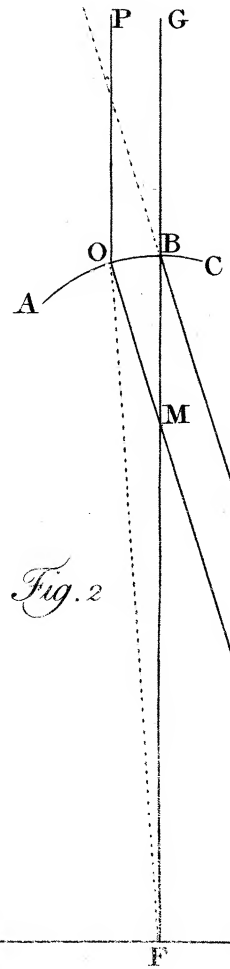
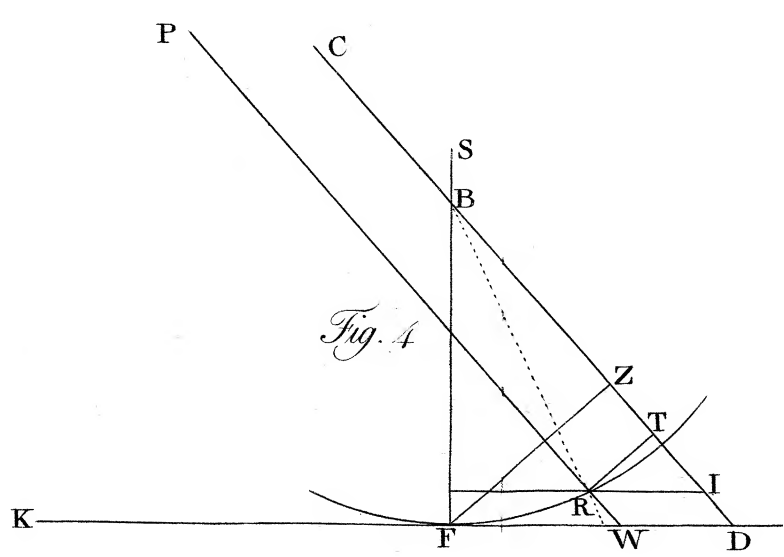
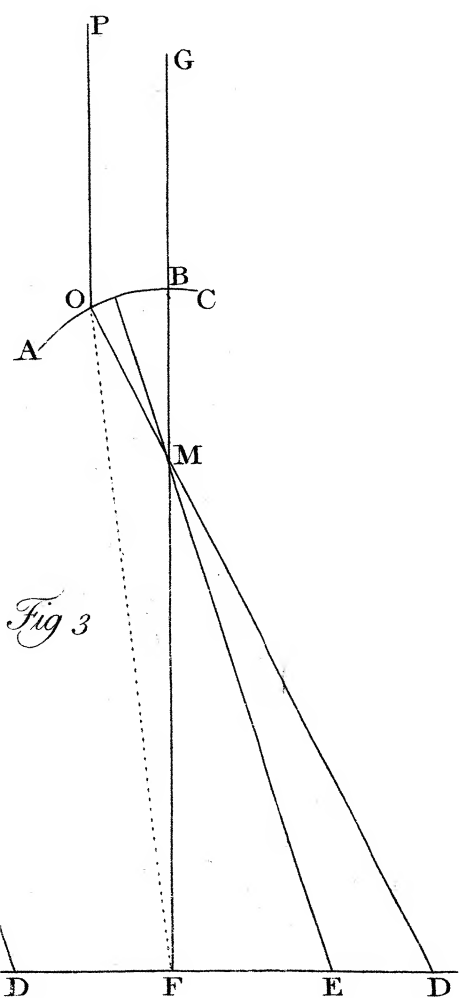


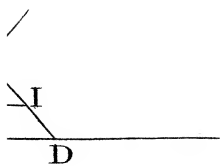
Fig. 2



Fig 3



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3 a.

